A COMPARATIVE STUDY OF FOUR DIFFERENT SCAVENGING SYSTEMS FOR NITROUS OXIDE

by

Rory Watson Morgan

A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

in

Public Health

Department of Family and Community Medicine

The University of Utah

June 1984

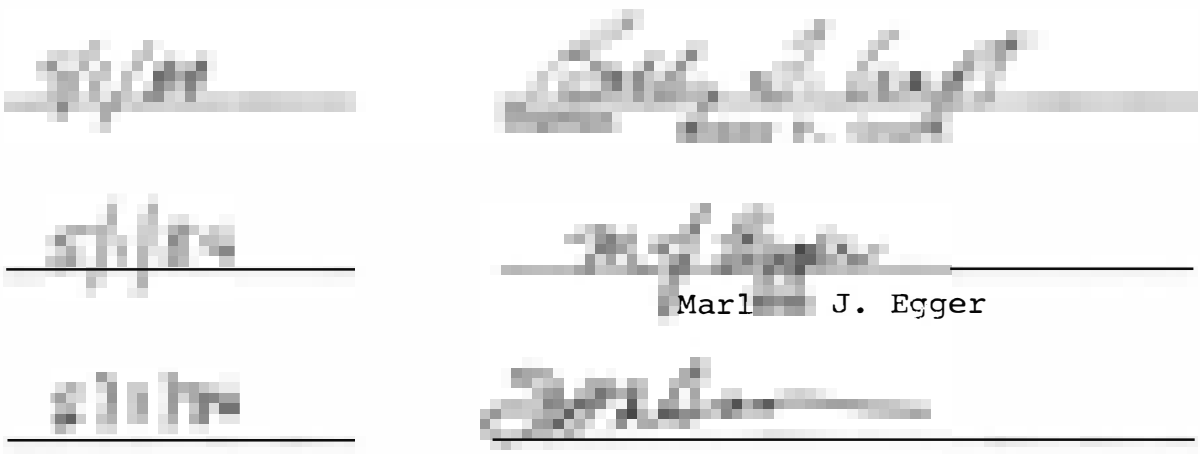
THE UNIVERSITY OF UTAH GRADUATE SCHOOL

SUPERVISORY COMMITTEE APPROVAL

of a thesis submitted by

Rory Watson Morgan

This thesis has been read by each member of the following supervisory committee and by majority vote has been found to be satisfactory.



Marl[illegible] J. Egger

James H. Nelson

THE UNIVERSITY OF UTAH GRADUATE SCHOOL

FINAL READING APPROVAL

To the Graduate Council of The University of Utah:

I have read the thesis of [redacted] Watson [redacted] in its final form and have found that (1) its format, citations, and bibliographic style are consistent and acceptable; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the Supervisory Committee and is ready for submission to the Graduate School.

[redacted]

[redacted] raft
Member, Supervisory Committee

Approved for the Major Department

[redacted]

C. Hilmon Castle
Chairman, Dean

Approved for the Graduate Council

[redacted]

James L. [redacted]
Dean of The Graduate School

ABSTRACT

A field investigation was conducted to evaluate and compare four of the commercially available scavenging systems for nitrous oxide in a dental operatory. In 1977, the National Institute for Occupational Safety and Health (NIOSH) recommended that no worker be exposed at time-weighted average concentrations greater than 50 parts per million in a dental office per administration. Since that time, several companies have developed scavengers to capture waste anesthetic gas. The scavenging systems tested in this study included the Brown, Blue, Porter, and the Fraser Harlake. The anesthetic gas analyzed in all measurements was nitrous oxide.

Twenty-minute personal air samples were taken from the dentist's breathing zone. Air samples were collected in a Tedlar bag (50 liters) using a personal air sampling pump operating at a flow rate of 2.0 liters per minute. The air sample was analyzed using a Wilks-Foxboro, Miran 1A Infrared Gas Analyzer. A pair of Nitrox dosimeters was taped side by side next to the open end of the Tygon tubing to test for similarity between the dosimeters and the Miran 1A results.

The results of the study indicated that the six pairs of scavengers were not statistically different at an overall

α = 0.05. Power calculations indicate high probability that a Type II Error resulted, since only 13 of the 30 patients (required to achieve this α-level) were obtained. The results suggest that, given a larger sample size and similar outcomes in the test results, there could be a difference between four of the six pairs. The results of all four scavengers exceeded the NIOSH recommendation of 50 parts per million.

Comparisons between the Nitrox dosimeters and the bag samples showed no statistically significant difference ($p > 0.10$). Also, no statistical significance was shown in the results of the paired Nitrox dosimeters ($p > 0.10$).

Dedicated to my wife Cynthia and our two children Gregory and Rachel.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The author very gratefully acknowledges his committee members, Dr. Bobby F. Craft, Ph.D., Marlene J. Egger, Ph.D., and James H. Nelson, Ph.D., for their assistance and direction throughout this thesis project. Sincere appreciation is especially extended to Harry Beaulieu, Ph.D., for sharing the idea of the study with the author and for providing part of the equipment to perform the study. Special appreciation is extended to the staff of the Utah Biomedical Testing Laboratory, particularly Neil Price, M.S., and Gene Turner, M.S., for their technical assistance and to R. S. Landauer, Jr., and Company for providing and analyzing the Nitrox passive monitors. Sincere thanks must also be extended to the several dentists and their staffs, especially the receptionists, for their time and patience in working with the author, for without their cooperation and interest this project could not have been done.

CHAPTER I

INTRODUCTION

Statement of the Problem

In the past 15 years, there has been considerable concern about chronic exposure of operating room personnel and dentists to nitrous oxide (N_2O). A number of epidemiologic studies have revealed increased incidences of miscarriage, birth defects, diseases of the kidney and liver, and neurologic disorders.[1,2,3]

In March 1977, the National Institute for Occupational Safety and Health (NIOSH) recommended that occupational exposure to nitrous oxide, when used in the hospital operatory, should be controlled so that no worker is exposed at time-weighted-average (TWA) concentrations greater than 25 parts per million (ppm) during anesthetic administration. NIOSH also indicated that, with currently available control technology, exposure levels of 50 ppm and less of nitrous oxide are attainable in dental offices.[4] These recommendations are based on a study by Whitcher, where the average concentration of nitrous oxide in a dental operatory was reduced from 900 ppm to 31 ppm by using one type of scavenging system. Whitcher pointed out that care must be taken in selecting the proper type of

equipment, since all equipment offered for sale is not equally safe or effective.[5]

The purpose of this research was to evaluate and compare four of the commercially available scavenging systems under similar conditions. The anesthetic gas analyzed in all measurements was nitrous oxide. The scavenging systems tested included:

BROWN SCAVENGING MASK	McKesson North Charleston, South Carolina 29411
BLUE MASK	Health Care Technology, Inc. 2328 F. Walsh Avenue Santa Clara, California 95051
CLEAN-AIR POLLUTION REDUCTION SYSTEM "PORTER"	Porter Instrument Company Hatfield, Pennsylvania 19440
FRASER HARLAKE	Fraser Harlake 145 Mid County Drive Orchard Park, New York 14127

The results of the study compared the relative performance of the four scavenger systems in controlling the waste anesthetic gas. The purpose of the study was not to endorse one product over another, nor were the scavengers tested the only scavenging systems available to the public. The four scavengers used in the study were the only scavenging systems known and available to the author.

Background

Chemical and Physical Properties

Nitrous oxide is a nonflammable, colorless gas with a slightly sweet taste and odor at high concentrations. It has a molecular weight of 44.02, boiling point of -88.44°C, and a molecular formula of N_2O. The specific gravity is 1.23; the vapor density is 1.5 (air = 1.0). Synonyms are nitrogen monoxide and laughing gas.

Nitrous oxide is prepared by heating ammonium nitrate crystals at 190°C until fused; then at 240°C, yielding nitrous oxide of approximately 95 percent purity.

$$NH_4NO_3 \xrightarrow{240^\circ C} N_2O + 2H_2O.$$

Impurities include nitrogen, nitric oxide, nitrogen dioxide, ammonia, and water vapor. While the U.S. Pharmacopoeia standard of purity indicates 97 percent as being permissible, at least 99.0 percent is usually obtained by modern purification processes.

For storage, nitrous oxide is compressed and liquified in blue cylinders capable of withstanding more than 1000 lb. sq. in., or 50 atm. Care must be taken in liquifying the gas that temperatures above 450°C are not reached during the liquifying process, since decomposition may result.

$$2N_2O \xrightarrow{450^\circ C} 2NO + N_2.$$

Except for decomposition at these temperatures, nitrous oxide is stable, does not react with soda lime or

anesthetic drugs or medical anesthesia equipment. It will, however, become impregnated in and diffuse through rubber.[6]

Toxicity and Physiological Effects

Toxic effects of nitrous oxide were first recognized in the early 1960s. Three different studies in the sixties showed embryotoxic and teratogenic effects of anesthetic agents in animals.[7,8,9] In 1963, Eastwood et al. studied bone marrow depression in humans after chronic exposure to nitrous oxide in patients with leukemia.[10] In 1967, Parbrook described how chronic exposure to high concentrations of nitrous oxide causes bone marrow depression.[11] In 1971, Bruce et al. summarized evidence that anesthesia interferes with the immune response after prolonged surgery.[12] In 1973, Corbett et al. reported that levels of 1000 ppm of nitrous oxide have lethal effects on embryos in pregnant rats.[13] In 1976, Kripke et al. demonstrated evidence of testicular damage in rats after a minimum of two days exposure to low concentrations of nitrous oxide.[14] In 1974 and 1975, Bruce et al. reported in two different experiments that exposure to concentrations of anesthetic gas mixtures of 500 ppm nitrous oxide/15 ppm halothane or 15 ppm enflurane and 500 ppm nitrous oxide alone resulted in decreased ability to perform complex tasks in cognitive and motor skills.[15,16]

Epidemiological Studies

It was in 1967 that the first case of adverse health effects from exposure to anesthetic gases was documented. Vaisman surveyed 303 Russian anesthesiologists and reported an unusually high incidence of headache, fatigue, irritability, nausea, and pruritus. He also noted that 18 of 31 pregnancies among the female anesthesiologists ended in premature delivery and one in congenital malformation.[17]

In 1970, Askog and Harvald reported a high rate of spontaneous abortion among anesthetists in Denmark. Their study revealed that approximately 20 percent of all pregnancies ended in spontaneous abortion, compared with a rate of approximately 10 percent among the same group prior to operating room employment.[18] In 1971, Cohen et al. reported a 38 percent abortion rate among physician anesthetists and a 30 percent abortion rate among operating room nurses, with a 10 percent abortion rate for control groups of other female physicians or general duty nurses. Miscarriages occurred earlier in gestation in both operating room nurses and anesthetists, compared with their control groups. Although there appeared to be a correlation between anesthetic gases and fetal lethality, none of these studies identified any specific anesthetic agent used in the operating room.[19]

In 1972, Knill-Jones et al. studied 563 married women anesthetists and 828 nonanesthetist married women physicians and found the frequency of spontaneous abortion

to be higher (18.2 percent) when the anesthetists were working than when they did not work (13.7 percent). The miscarriage rate in the control group was 14.7 percent. The incidence of congenital abnormalities was also higher when the mother worked; 12 percent of anesthetists and 5.4 percent of the controls suffered involuntary infertility.[20]

In 1973, Corbett et al. surveyed 621 female nurse anesthetists in Michigan. The incidence of malignancy among the group was three times the expected rate. The survey also revealed a higher incidence of birth defects among children of the nurse anesthetists. The overall incidence of congenital abnormalities was significantly higher when the mother practiced during pregnancy than when the mother did not practice (16 vs. 6 percent).[21,22]

In 1974, Cohen et al. reported in a national study entitled "Occupational Disease Among Operating Room Personnel" that the risk of spontaneous abortion was increased for women exposed to the operating room environment during the first trimester of pregnancy and the preceding year. The risk was estimated to be 1.3 to 2 times that of unexposed personnel. There was evidence for an increased risk of congenital abnormalities among the live-born babies of exposed female respondents. An intragroup analysis of the exposed nurse anesthetists compared with the unexposed members of the group indicated an increase of more than 60 percent ($p < 0.01$) of congenital abnormalities. There was also an increase of 25 percent

in the incidence of congenital abnormalities among children born to the wives of exposed male physician anesthetists ($p = 0.04$). Statistically significant values were also found for cancer, hepatic, and renal disease rates.[23] It should be noted that no scavenging systems were mentioned in the reporting of these surveys.

In 1975, Cohen et al. reported the first survey of anesthetic health hazards among dentists. Although the survey size was small, it did show a 78 percent increase of spontaneous abortion in spouses of exposed dentists and a significant increase (156 percent) in liver disease for exposed dentists. Congenital abnormalities, cancer, and kidney diseases were also greater for exposed dentists, but the differences were not statistically significant.[24]

In 1980, Cohen et al. reported in a much larger survey of some 30,650 dentists and 30,547 chairside assistants the health effects of chronic exposure to trace anesthetic gases, in particular nitrous oxide. The study showed a 50 percent increase in spontaneous abortion among the wives of male dentists if the male had been heavily exposed to inhalation anesthetics during the year prior to conception. Heavy exposure was defined as an excess of eight hours of exposure per week of nitrous oxide. A 1.7- to 2.3-fold increased rate of spontaneous abortion was reported among female chairside assistants who experienced heavy exposure. There was no difference in the reported increased incidence of congenital abnormalities between exposed and unexposed

dentists. This was in contrast to that which was reported by male physician anesthetists exposed in the operating room. It must be remembered that physicians use halogenated agents extensively, whereas most dentists limit their use of inhalation anesthetics to nitrous oxide alone. Other health effects noted consisted of a twofold increase in musculoskeletal disease among children of the exposed female chairside assistants, a 2.4-fold significant increase in cancer of the cervix among female chairside assistants who were heavily exposed to inhalation anesthetics, a 1.7-fold increase in liver disease for heavily exposed male dentists, and a 1.6-fold increase in liver disease for similarly exposed female chairside assistants. The study showed a 1.2-fold increase in kidney disease for male dentists exposed to nitrous oxide and a 1.2- to 1.7-fold increase for female chairside assistants exposed to nitrous oxide. In male dentists, the increase in neurologic disease was 1.2- to 1.9-fold, and, in female chairside assistants, the increase reached 1.7- to 2.8-fold for those exposed to nitrous oxide.[25]

Occupational Exposure of Dentists to Nitrous Oxide

The fact that the offspring of operating room personnel experienced higher levels of congenital abnormalities than the offspring of dental personnel could be a result of the mixtures of anesthetic gases used in the

operating rooms and the difference between the levels of nitrous oxide present in the air. Common anesthetic agents used in operating rooms include gases such as halothane, enflurane, and nitrous oxide; whereas the dental operatory restricts its use to nitrous oxide alone. Nitrous oxide concentrations have been shown to be (2- to 3-fold) greater in the dental operatory as compared to the hospital operating room. Therefore, this suggests that the increased incidence in congenital abnormalities is a result of the other anesthetic agents used in the operating room and not to the nitrous oxide. These nitrous oxide exposures in the dental operatory have been reported in six different studies.[26,27,28,29,30,31] Peak mean levels ranged from 401 ± 357 ppm to 6767 ± 4527 ppm in the six reported studies. All of the values were determined by breathing zone samples collected for varying amounts of time. None of the studies indicated that any type of scavenging system was in use during the monitoring. In 1977, Campbell et al. reported an eight-hour TWA of 785 ppm for one particular dental operatory.[32]

Summary

In summary, several studies have documented extremely high levels of nitrous oxide in the dental operatory. Studies have also documented adverse health effects among those exposed in these environments. Therefore, these

facts indicate an urgent need for control measures to reduce nitrous oxide exposures to the dentist and his/her staff.

Endnotes

[1]Ellis N. Cohen et al., "Occupational Disease Among Operating Room Personnel: A National Study," Anesthesiology 41 (October 1974):335.

[2]Ellis N. Cohen et al., "A Survey of Anesthetic Health Hazards Among Dentists," The Journal of American Dental Association 90 (June 1975):1294.

[3]Ellis N. Cohen et al., "Occupational Disease in Dentistry and Chronic Exposure to Trace Anesthetic Gases," The Journal of American Dental Association 101 (July 1980): 28-30.

[4]National Institute of Occupational Safety and Health, Criteria for a Recommended Standard--Occupational Exposure to Waste Anesthetic Gases and Vapors, DHEW (NIOSH) Publication No. 77-140 (1977), p. 194.

[5]Charles E. Whitcher et al., "Control of Occupational Exposure to Nitrous Oxide in the Dental Operatory," U.S. Department of Health, Education and Welfare, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 77-171 (April 1977), p. 37.

[6]Douglas W. Eastwood, Nitrous Oxide (Philadelphia: F. A. Davis Company, 1964), p. 24.

[7]B. Raymond Fink, T. H. Shepard, and R. J. Blandau, "Teratogenic Activity of Nitrous Oxide," Nature 214 (April 8, 1967):146.

[8]Alice B. Bashford and B. Raymond Fine, "The Teratogenicity of Halothane in the Rat," Anesthesiology 29 (December 1968):1167.

[9]Bradley E. Smith, Margaret L. Gaub, and Frank Moya, "Investigation into the Teratogenic Effects of Anesthetic Agents: The Fluorinated Agents," Anesthesiology 26 (April 1965):260.

[10]Douglas W. Eastwood et al., "Effects of Nitrous Oxide on the White-Cell Count in Leukemia," The New England Journal of Medicine 268 (February 7, 1963):297.

[11]Geoffrey D. Parbrook, "Leucopenic Effects of Prolonged Nitrous Oxide Treatment," British Journal of Anaesthesia 39 (1967):124.

[12]David L. Bruce and Daniel W. Wingard, "Anesthesia and the Immune Response," Anesthesiology 34 (March 1971): 274.

[13]Thomas H. Corbett et al., "Effects of Low Concentrations of Nitrous Oxide on Rat Pregnancy," Anesthesiology 39 (September 1973):300.

[14]Benjamin J. Kripke et al., "Testicular Reaction to Prolonged Exposure to Nitrous Oxide," Anesthesiology 44 (February 1976):107.

[15]David L. Bruce, Mary Jean Bach, and Jack Arbit, "Trace Anesthetic Effects of Perceptual, Cognitive, and Motor Skills," Anesthesiology 40 (May 1974):457.

[16]David L. Bruce and Mary Jean Bach, "Psychological Studies of Human Performance as Affected by Traces of Enflurane and Nitrous Oxide," Anesthesiology 42 (February 1975):196.

[17]A. I. Vaisman, "Working Conditions in Surgery and Their Effects on the Health of Anesthesiologists," Eksp Khir Anesteziol 3 (1967):44-49.

[18]V. Askog and B. Harvald, "Teratogen Effect of Inhalations-Anestetika," Saertyk Nord Med 3 (1970):490-500.

[19]Ellis N. Cohen, J. Weldon Bellville, and Byron W. Brown, "Anesthesia, Pregnancy, and Miscarriage: A Study of Operating Room Nurses and Anesthetists," Anesthesiology 35 (October 1971):345.

[20]R. P. Knill-Jones, D. B. Moir, and L. V. Rodrigues, "Anaesthetic Practice and Pregnancy: A Controlled Survey of Women Anesthetists in the United Kingdom," The Lancet 2 (November 1972):1326.

[21]Thomas H. Corbett et al., "Incidence of Cancer Among Michigan Nurse-Anesthetists," Anesthesiology 38 (March 1973):262.

[22]Thomas H. Corbett et al., "Birth Defects Among Children of Nurse-Anesthetists," Anesthesiology 41 (October 1974):342.

[23]Ellis N. Cohen et al., "Occupational Disease Among Operating Room Personnel: A National Study," Anesthesiology 41 (October 1974):335.

[24]Ellis N. Cohen et al., "A Survey of Anesthetic Health Hazards Among Dentists," The Journal of American Dental Association 90 (June 1975):1294.

[25]Ellis N. Cohen et al., "Occupational Disease in Dentistry and Chronic Exposure to Trace Anesthetic Gases," The Journal of American Dental Association 101 (July 1980): 28-30.

[26]Robert I. Millard and Thomas H. Corbett, "Nitrous Oxide Concentration in the Dental Operatory," Journal of Oral Surgery 32 (August 1974):594.

[27]Ralph D. Swenson, "Scavenging of Dental Anesthetic Gases," Journal of Oral Surgery 34 (March 1976):212.

[28]Robert L. Campbell et al., "Exposure to Anesthetic Waste Gas in Oral Surgery," Journal of Oral Surgery 35 (August 1977):626-627.

[29]Charles E. Whitcher et al., "Control of Occupational Exposure to Nitrous Oxide in the Dental Operatory," The Journal of American Dental Association 95 (October 1977): 772-773.

[30]P. Cleaton-Jones et al., "Nitrous Oxide Contamination in Dental Surgeries Using Relative Analgesia," British Journal of Anaesthesia 50 (1978):1020-1022.

[31]J. Scaramella et al., "Nitrous Oxide Pollution Levels in Oral Surgery Offices," Journal of Oral Surgery 36 (June 1978):442.

[32]Robert L. Campbell et al., "Exposure to Anesthetic Waste Gas in Oral Surgery," Journal of Oral Surgery 35 (August 1977):627.

CHAPTER II

METHODS AND MATERIALS

Types of Scavengers and Functions

The typical scavenging system used by the dentist removes excess nitrous oxide via a vacuum hose connected to the nosepiece of a mask used to administer the anesthetic gas. The vacuum scavenges the gas exhaled by the patient as well as any excess gas from the analgesia machine that might leak around the edges of the mask. A vacuum flowrate of 35 to 45 liters per minute (lpm) is recommended by most manufacturers to prevent any significant nitrous oxide leakage into the room air. However, only two of the four scavengers (Brown and Porter) had any type of flow measuring device to indicate the vacuum flowrate. The scavenging units tested are offered with various sized nosepieces.

BROWN	Adult, child
BLUE	One size only
PORTER	Adult, child
FRASER HARLAKE	Large, medium, small

The Blue scavenger consists of a compact double mask system. The inner mask is contained within the slightly larger outer mask, and a slight vacuum is present in the space between the masks. Two large hoses supply the

N_2O/O_2 mixture to the inner mask. Two smaller hoses connected to the space between the two layers remove the waste anesthetic gas. The mask is made of a lightweight, flexible rubber.

The Brown scavenger also consists of a compact double mask system. The inner mask is contained within a slightly larger outer mask, and a slight vacuum is present in the space between. Two large hoses supply the N_2O/O_2 mixture to the inner mask. Two smaller hoses connected to the space between the two layers remove the waste anesthetic gas. The mask contains a round, one-way valve located in the inner mask, which opens to the outer mask only during expiration. The mask also has two small holes at the bottom of the outer mask, whose purpose is to capture any escaping gas from around the mask. The Brown mask is thinner, more lightweight and flexible than the Blue mask. The fit between the outer and inner mask is not as tight as that of the Blue mask. The Brown scavenger has a flowmeter connected to the vacuum tubing which is used to regulate the suction at the recommended flowrate. The adult-size face mask was tested in the study.

The Porter mask consists of a single hood made of a soft foam rubber, with a hard, rigid border that fits around the nose. One large hose delivers the N_2O/O_2 mixture to one side of the mask, while another large hose on the opposite side removes the exhaled air. The mask

has two molded air intakes located on each side of the outer mask to remove any escaping gas. The Porter scavenger has a flowmeter connected to the vacuum system which is used to regulate the suction at the recommended flowrate. The adult-size face mask was tested in the study.

The Fraser Harlake mask consists of a single hood made of a soft, pliable rubber. The N_2O/O_2 mixture is delivered by a large hose on one side of the mask and removed by another hose on the opposite side of the mask. An annular opening around the circumference of the cone collects gases leaking from the edges of the nasal hood. The large-size face mask was tested in the study.

Test Protocol

The experimental design consisted of comparing the performance of each of the four scavengers when evaluated under as similar conditions as possible in a dental office. Each scavenger was used on the same patient during similar procedures on four separate office visits. Since the purpose of the study was to evaluate the four separate scavengers and not to determine a time-weighted-average (TWA) exposure to the dentist, it was decided to choose a sampling time that was most typical to dental procedures. Twenty minutes was judged to be a sufficient sampling time to give an accurate indication of the performance of each scavenger.

Statistics and Sample Size

With regard to statistics, one would like to analyze the data using analysis of variance (ANOVA) on the log concentrations. Plots were made to determine whether or not the log transformation was appropriate. However, ANOVA is not the correct analysis here. ANOVA requires independent errors, whereas the experimental design uses the same patients for each scavenger. Matched experimental designs require matched analyses. Therefore, all possible paired (dependent sample) t-tests were used, with the overall α controlled by Bonferroni's inequality.[1] A competing analysis would be repeated measures ANOVA, but it would still be followed by Bonferroni t-tests of all possible pairs of scavengers. The repeated measures analysis would have to be done on the computer and was judged to be unnecessary, since it is the individual comparisons between pairs of scavengers that are of interest here.

For the purpose of determining the number of patients needed for a suitable comparison of the four scavengers, data from a previous preliminary study performed by Beaulieu were used.[2] From that study, a standard deviation (SD) of the nitrous oxide concentrations among the four scavengers was estimated to be 1000 ppm. It was desired that the present study would have 80% power to detect a difference of 1200 ppm among the four scavengers.

Since conditions and results varied greatly in the Beaulieu study, it was decided to recalculate the sample size based on the results obtained from the first five patients in this study. It was hoped that the sample size could be reduced by the improved estimate of the new SD.

It was also decided to calculate a new sample size based on the mean of the sample differences ($\bar{d}$) and the sample standard deviation of the differences (S_d) between the pair of scavengers with the smallest sample difference of the mean. As can be seen in Table 1, the pair with the smallest difference of the sample mean was the Brown and Fraser Harlake scavengers. A sample size of over 700 patients would be required to demonstrate statistical significance from this pair. This was not reasonable for this study. Therefore, the pair with the second smallest sample difference of the mean was selected to calculate the required sample size at 80% power. This pair was the Brown and Blue scavengers. If statistical significance could be shown between this pair with their required sample size, then statistical significance would be achieved for all the other pairs aside from the Brown and Fraser Harlake. However, the reduction in difference between sample means relative to the observed S_d produced a required sample size of n = 30, which was larger than the initial estimate.[3] The S_d was 526 ppm and the $\bar{d}$ was 337 ppm between the Brown and Blue scavengers for the data derived from the first five patients (see Table 2).

TABLE 1

BAG SAMPLE RESULTS OF FIRST FIVE PATIENTS
(Results Recorded in Parts Per Million of N_2O)

Patient	Brown	Blue	Porter	Fraser Harlake
1	369	184	13,239	1,276
2	101	59	8,823	415
3	397	189	2,620	286
4	1,325	61	1,702	428
5	416	428	807	632
$\bar{X} \pm SD$	521 ± 467	184 ± 150	5,438 ± 5,377	607 ± 394

TABLE 2

MEAN OF THE SAMPLE DIFFERENCES ($\bar{d}$) AND SAMPLE STANDARD DEVIATION OF THE DIFFERENCES (S_d) BETWEEN THE BROWN AND BLUE SCAVENGERS FOR THE FIRST FIVE PATIENTS
(Results Recorded in Parts Per Million of N_2O)

Patient	Brown	Blue	Difference
1	369	184	185
2	101	59	42
3	397	189	208
4	1,325	61	1,264
5	416	428	-12
$\bar{d} \pm S_d$			337 ± 526

It was realized after several months of testing that the sample size of 30 was also unreasonable due to time and financial constraints. Therefore, the study was terminated after obtaining measurements on 15 patients.

Sample Selection

The selection of dentists participating in the study resulted from contacts obtained from the telephone directory and from a request published in a newsletter of the local chapter of the Utah Dental Association, Salt Lake District Dental Society. Not all of the dentists contacted had patients who met the requirements of the study.

Sampling Procedure

A personal air sample was taken from the dentist's breathing zone during the initial twenty minutes of work on the patient. Air samples were collected in a Tedlar bag (50 liters) using a personal air sampling pump (Dupont P-4000) operating at a flowrate of 2.0 lpm. A total sample volume of 40 liters was collected. The sampling train consisted of three feet of Tygon tubing attached to the dentist's right collar at one end and the other end connected to the pump inlet. A second length of Tygon (eight feet) led from the pump outlet to the Tedlar bag (see Figure 1).

To control as many variables as possible, several parameters were kept constant throughout the study. The

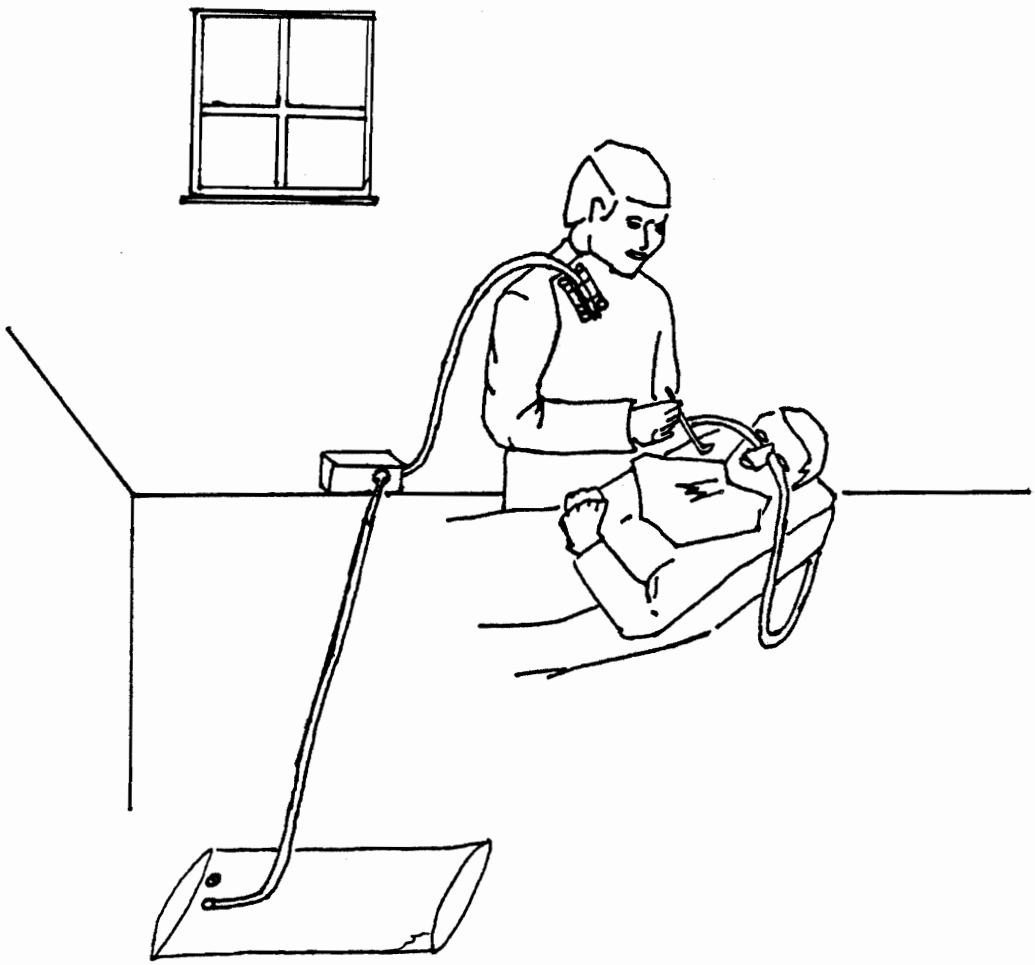


Fig. 1. Nitrous oxide sampling system. Two Nitrox dosimeters were taped together next to open end of Tygon tubing.

same room and chair were used in each respective dental office. The dentist selected the percent of nitrous oxide required for each patient before the initial sampling. That percent of nitrous oxide was maintained for that particular patient during all four visits. The concentration of nitrous oxide ranged between 42 and 46 percent for all the patients in the study. To prevent any variability due to the different types of flowmeters available in the different dental offices, the Porter flowmeter was used in all possible situations. During each visit a different scavenging system was connected to the flowmeter. The flowrate and percent of N_2O/O_2 administered was controlled by the flowmeter. The flowmeter consisted of two inlets for the gases, two rotameters, and a valve that fed the gas mixture to the rubber tubing of the scavenger (see Figure 2).

Each bag sample was analyzed by a calibrated, Wilks-Foxboro Miran 1A Infrared Gas Analyzer. The absorbance reading was recorded on a strip chart recorder and in a log book. Corresponding concentrations in ppm were also recorded on the strip chart recorder and in a log book. After each test, the bag was flushed twice with laboratory air in order to clean the bag of any remaining gases.

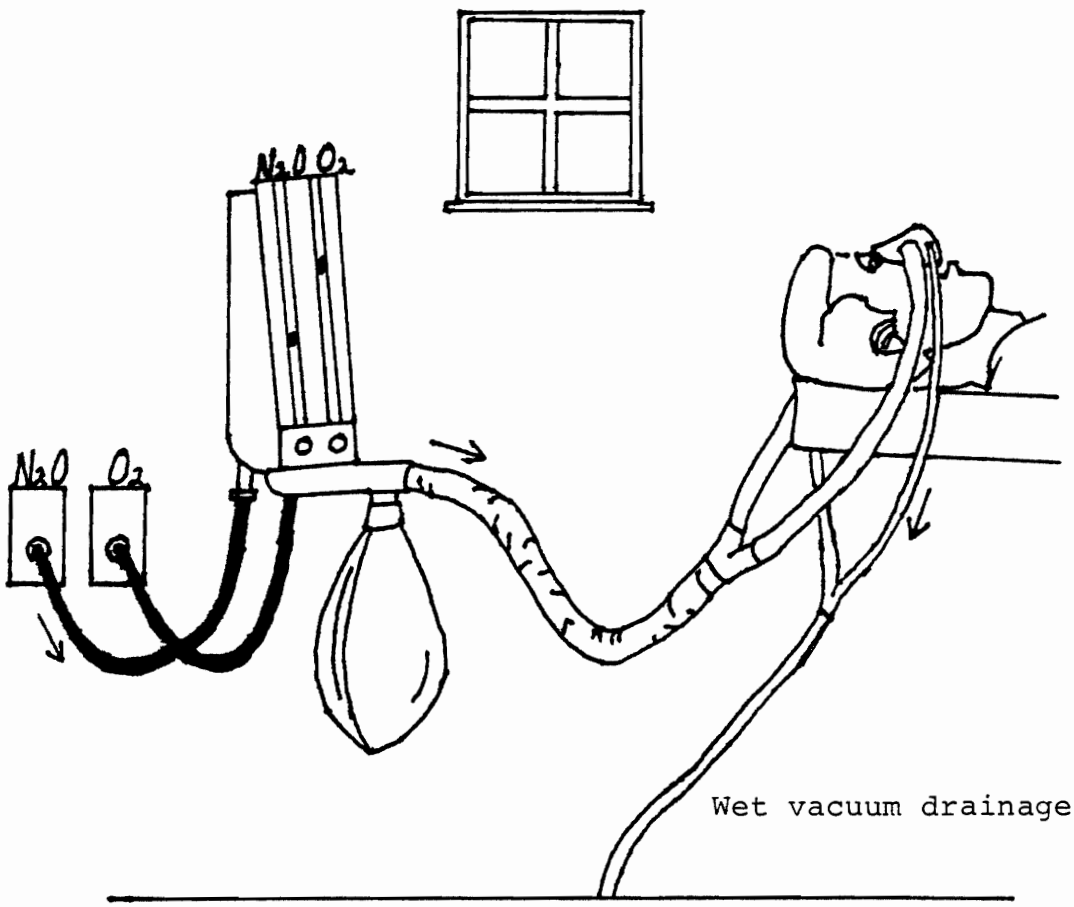


Fig. 2. Typical dental scavenging apparatus. Arrows indicate direction of flow of the gas.

Analytical Method

The Miran 1A was used to evaluate the concentrations of nitrous oxide in each bag. A Cell Pathlength of 0.75 meters was chosen to obtain a complete range of concentrations from 0 to 30,000 ppm on the absorbance scale of 0.0 to 1.0 absorbance units.

The principle of operation of the Miran 1A is absorption of infrared light (IR) at a wavelength specific for the gas under analysis, 4.5 micrometers for nitrous oxide. A fan continuously passes the air being analyzed through the sampling cell. An infrared light beam is simultaneously transmitted through the same cell. Variations in concentrations of nitrous oxide result in proportionate changes in the quantity of transmitted IR energy. This is sensed by a detector and then amplified and displayed. A bag sample of approximately 40 liters provides more than seven air changes in the 5.64 liter cell of the Miran 1A. A minimum of five air changes is required for the Miran 1A to detect and stabilize the concentration in the cell.

Calibration of the Miran 1A was accomplished by the closed-loop calibration system developed by Wilks-Foxboro. The calibration system consists of a stainless steel bellows pump, septum, stainless steel fittings, and polytetrafluorethylene (PTFE) connecting tubes. Known concentrations of nitrous oxide were introduced through a

septum by gas syringes and circulated through the cell by means of the pump. Gas sample concentrations in ppm were determined by the formula

$$C \text{ (ppm)} = \frac{V}{5.64}$$

where V = sample volume in microliters. The Miran 1A was calibrated over the range from 0.0 to 30,000 ppm, which resulted in sample volumes in milliliters ranging from 0.5 ml to 150 ml. Therefore, the formula was adjusted as follows:

$$C \text{ (ppm)} = \frac{V(1.0 \times 10^3)}{5.64}$$

where V = sample volume in milliliters.

The Miran 1A was initially calibrated in the laboratory. A range of absorbance units was determined by injecting known volumes of nitrous oxide gas. The calibration curve was then tested for accuracy by circulating through the cell four separate known volumes (in ppm) of nitrous oxide from cylinders of Matheson Calibrated Gas. The concentrations of the four cylinders of nitrous oxide used for the first calibration check were 150 ppm, 523 ppm, 2,544 ppm, and 11,000 ppm. The concentrations of the four cylinders of nitrous oxide used for the second and third calibration checks were 150 ppm, 486 ppm, 2,544 ppm, and 11,000 ppm. Measured absorbance units for each gas were used to determine the concentration of each gas by use of the predetermined calibration curve. Differences between calibrated and actual levels in ppm were recorded as percent

error (see page 48, Appendix A). The Miran 1A was moved twice; therefore, three separate calibration curves and checks were performed during the study (see pages 45-48 and 49-50, Appendix A).

Prior to the analysis of each sample, the calibration curve was checked by injecting two separate known volumes of nitrous oxide into the Miran 1A. Fresh air was used to flush out the cell and zero the instrument after each injection of nitrous oxide. After each bag was analyzed, the absorbance value observed for the sample was bracketed by appropriate absorbance values obtained by injecting appropriate known volumes of nitrous oxide. The concentration of the sample was then calculated from the calibration curve. Total system accuracy was estimated at worse case to be $\pm$5.3% after the initial calibration, $\pm$8.5% after the second calibration, and $\pm$3.8% after the third calibration check.

Nitrox Dosimeter

The recent understanding of potential harmful effects of nitrous oxide as a gaseous anesthetic in medical and dental applications has resulted in the need to evaluate more precisely and to control more accurately levels of nitrous oxide. Due to the difficulty of measuring nitrous oxide levels in sometimes confined places with the traditional pump, tubing, and bag, a new and simpler method for sampling nitrous oxide has been developed. The Nitrox

dosimeter and analytical system were developed to meet the need for a reliable and convenient nitrous oxide monitoring program. The Nitrox dosimeter, marketed by R. S. Landauer, Jr., & Company, was included in this study to field test the dosimeters and to provide additional nitrous oxide measurement information. Side-by-side comparisons were made between results obtained with the dosimeter and the sampling bag.

The Nitrox dosimeter operates as a self-contained passive sampler worn by the dentist in the shirt pocket or on the shirt collar. When uncapped, the Nitrox dosimeter samples nitrous oxide from its environment by diffusion of nitrous oxide through a specially designated inlet section. The nitrous oxide that diffuses into the dosimeter is collected on activated molecular sieve contained within stainless steel cartridges with openings at both ends. After exposure, the Nitrox dosimeter is capped and returned to the manufacturer for analysis. The stainless steel cartridges are removed from the dosimeter and analyzed with a thermal desorption system equipped with an infrared gas analyzer.

The Nitrox dosimeter has been shown to perform satisfactorily under a variety of laboratory test conditions and in operating room field tests. This device can be used for monitoring a wide range of nitrous oxide concentrations for up to 40 hours. The higher the nitrous oxide

concentration, the smaller the exposure interval necessary to quantitate an exposure concentration.

Bag sampling had already begun in the dental offices before the dosimeters were included in the study. The right shirt collar was chosen as the location to clip on the Tygon tubing. The first ten dosimeters did not have clips; therefore, they were placed in the shirt or jacket pocket of the dentist. The pocket happened to always be on the left side of the dentist. Results from the dosimeters were compared to the results from the bag samples. Since the Nitrox results for the first ten dosimeters agreed only within ±50% with those obtained with the bag sampling, it was then decided that the dosimeters should be taped next to the Tygon tubing on the right shirt collar. Therefore, any dissimilarity in data could be attributed primarily to error in sampling or analysis and not to proximity to the source. It was also decided to tape two dosimeters next to each other on the end of the Tygon tubing, to determine any variability between the Nitrox dosimeters. The sampling configuration was changed after the sixth dosimeter had been used from the second set of ten dosimeters. After each set of ten dosimeters was used, the Nitrox dosimeters were sent to R. S. Landauer, Jr., & Company for analysis.

Endnotes

[1]Rupert G. Motler, Simultaneous Statistical Inference (New York: Springer-Verlag, 1981), pp. 67-70.

[2]Harry J. Beaulieu, "Evaluation of Nitrous Oxide Scavenging System," Unpublished manuscript, Department of Community and Environmental Health, Boise State University, Boise, Idaho.

[3]Theodore Colton, Statistics in Medicine (Boston: Little, Brown and Company, 1974), p. 142.

CHAPTER III

RESULTS

Results are shown in Tables 3-5. Table 3 presents the differences between each of the four scavengers for both the bag samples and the Nitrox dosimeters. Fifteen patients were studied, but missing values reduced the effective sample size to 13 for both the bag samples and the Nitrox dosimeters. This was due to equipment malfunction on the last tests of patients nine and ten with the bag samples. The author had not yet received the Nitrox dosimeters for the first tests of patients one and three; therefore, only 13 patients were included in calculating the results for the Nitrox dosimeters.

TABLE 3

SCAVENGER COMPARISON FOR BAG SAMPLES AND NITROX DOSIMETERS
(N=13 for Bag Samples and N=13 for Nitrox Dosimeters)
(Results Recorded in Parts Per Million of N_2O)

Scavenger	Bag Sample $\bar{X} \pm SD$	Passive Dosimeter $\bar{X} \pm SD$
Brown	492 ± 347	946 ± 740
Blue	451 ± 545	543 ± 692
Porter	4,613 ± 4,668	4,656 ± 6,086
Fraser Harlake	933 ± 724	1,105 ± 747

TABLE 4

MEAN OF THE SAMPLE DIFFERENCES AND SAMPLE STANDARD DEVIATION OF THE DIFFERENCES BETWEEN ALL POSSIBLE PAIRS OF BAG SAMPLES (N=13 for Bag Samples; Results Recorded in Parts Per Million of N_2O)

	Brown vs Blue	Porter vs Brown	Fraser Harlake vs Brown	Porter vs Blue	Fraser Harlake vs Blue	Porter vs Fraser Harlake
$\bar{d} \pm s_d$	41 ± 600	$4,121 \pm 4,739$	441 ± 890	$4,162 \pm 4,859$	482 ± 705	$3,680 \pm 4,892$
p-value	$p>0.10$	$0.0083<p<0.01$	$0.05<p<0.10$	$0.0083<p<0.01$	$0.02<p<0.05$	$0.01<p<0.02$

TABLE 5

MEAN OF THE SAMPLE DIFFERENCES AND SAMPLE STANDARD DEVIATION OF THE DIFFERENCES BETWEEN ALL POSSIBLE PAIRS OF NITROX DOSIMETERS (N=13 for Nitrox Dosimeters; Results Recorded in Parts Per Million of N_2O)

	Brown vs Blue	Porter vs Brown	Fraser Harlake vs Brown	Porter vs Blue	Fraser Harlake vs Blue	Porter vs Fraser Harlake
$\bar{d} \pm s_d$	$403 \pm 1,063$	$3,710 \pm 5,964$	$159 \pm 1,527$	$4,113 \pm 5,933$	562 ± 740	$3,551 \pm 5,877$
p-value	$p>0.10$	$0.02<p<0.05$	$p>0.10$	$0.02<p<0.05$	$0.01<p<0.02$	$0.05<p<0.10$

Tables 4 and 5 indicate the statistical difference between all possible pairs of scavengers. The two tables show the mean of the sample differences ($\bar{d}$) and the sample standard deviation of the differences (S_d) between all possible pairs of the four scavengers. Concentrations of nitrous oxide were plotted for each pair of scavengers to determine whether a log transformation was appropriate; it was not. The results in Tables 4 and 5 were used to calculate a matched pairs, two-tailed t-test based on the t-distribution with n - 1 degrees of freedom (df). Statistical significance was measured at $\alpha^1 = 0.0083$ for each pair in order to preserve an overall 5% significance level for the entire study, in accordance with the Bonferroni method of multiple comparisons.[1]

Table 4 shows the results of the bag samples. (The individual nitrous oxide concentrations for each bag sample of the patients are found in Table 11, Appendix B. Table 11 also indicates the percent of nitrous oxide that each patient received and the average N_2O/O_2 flowrate delivered to each patient.) The differences between each of the six pairs of scavengers in Table 4 were determined by subtracting the scavenger with the smaller average nitrous oxide concentration from the scavenger with the larger average concentration, e.g., Brown minus Blue. The results in Table 4 indicate that no statistical significance exists between the difference among all six pairs of scavengers,

as is expected from the very small achieved number of patients. Two of the six pairs clearly indicate no statistical difference between each scavenger ($p > 0.10$). These two pairs were the Brown and Blue scavengers and the Brown and Fraser Harlake scavengers. However, the t-values for four of the six pairs were close to the tabled t-values for obtaining $p = 0.0083$, suggesting that a Type II Error may have been committed due to the small number of patients. A Type II Error is defined as the chance of erroneously failing to reject a null hypothesis that is, in fact, false. If the null hypothesis is false, then the alternate hypothesis is, in reality, the correct result. The alternate hypothesis indicates that the two scavengers do not collect equal concentrations of nitrous oxide. Power calculations support the likelihood of a Type II Error; in particular, a sample size of 30 patients instead of 13 would have been sufficient to achieve statistical significance ($p < 0.001$) for the results shown in Table 4 for four of the six pairs of scavengers. These four pairs were Porter vs. Brown, Porter vs. Blue, Fraser Harlake vs. Blue, and Porter vs. Fraser Harlake. Therefore, if a sample size of 30 patients had been achieved, and if the results were similar to those obtained with 13 patients, then statistical significance would have been likely for four of the six pairs of scavengers.

Data in Table 5 are based on the nitrous oxide concentrations as determined from the Nitrox dosimeters. (The individual nitrous oxide concentrations for each test of the patients are found in Table 12, Appendix B. Table 12, like Table 11, indicates the percent of nitrous oxide that each patient received and the average N_2O/O_2 flowrate delivered to each patient.) Forty-four of the 60 sample test results were an average of two Nitrox dosimeters taped together. Comparisons between the two Nitrox dosimeters and the comparison between the two dosimeters and the bag samples are discussed in Chapter 4.

The results in Table 5 indicate somewhat the same results as were shown in Table 4. No statistical significance exists between any of the six pairs of scavengers. The t-values for four of the six pairs were also close to the tabled t-values for obtaining $p = 0.0083$. Two of the six pairs clearly indicated no statistical difference between each scavenger ($p > 0.10$. These two pairs were also the Brown and Blue scavengers and the Brown and Fraser Harlake scavengers. Again, it was likely that a Type II Error occurred due to insufficient numbers of patients. Type II Error was likely for Porter vs. Brown, Porter vs. Blue, Fraser Harlake vs. Blue, and Porter vs. Fraser Harlake.

Endnotes

[1]Rupert G. Miller, Simultaneous Statistical Inference (New York: Springer-Verlag, 1981), pp. 67-70.

CHAPTER IV

DISCUSSION

Proper Scavenging Technique

As stated in the introduction, the purpose of the study was to compare the relative performance of the four scavengers and not to endorse one product over the other. In reference to the NIOSH recommendation of 50 ppm per administration, none of the four scavengers performed adequately. All bag samples for nitrous oxide were in excess of 50 ppm, and only three Nitrox dosimeter results were below 50 ppm. During the course of the study, certain work practices were observed that may be helpful in improving the efficiency of the scavenger.

First, the proper handling and fitting of the scavenger mask is essential in reducing exposure to dental operatory personnel. The mask must always be placed on the patient before administering the nitrous oxide. It is recommended that only the oxygen be used while adjustments for gaps and leaks are made for the proper fit. After a proper fit is obtained, the nitrous oxide can be administered to the patient. A connection should be made to secure the rubber tubing that is leading away from both sides of the mask. This connection should be made underneath the dental

chair in order to cause a tight, snug fit of the mask onto the patient's face. All efforts should be made by the dentist not to remove the mask while the gas is flowing to the patient. As the dental procedure comes to an end, the nitrous oxide should be turned off first, while oxygen continues to flow to the patient. The oxygen should then be turned off and the mask removed. This simple procedure will help to minimize exposures.

Proper equipment is also important in reducing nitrous oxide exposure. Two factors related to equipment are important: 1) obtaining proper suction, and 2) accurate regulation of that suction. In most dental offices, the suction from the scavenger mask leads to a wet vacuum drainage, the same suction and drainage hook up that is used to clean the patient's mouth. There are two problems associated with this type of arrangement. The first is not having a means to measure the proper vacuum flowrate that is going through the scavenger. Most manufacturers recommend a vacuum flowrate of 35 to 45 lpm. The high pressure vacuum system used by the dentist is much higher. If too much vacuum is used, the suction empties the oxygen bag and causes a negative pressure on the mask, which prevents the patient from breathing. If too little vacuum is used, then the excess gas escapes into the room. Therefore, it is recommended that a flowmeter and a regulator valve be installed in the suction line to better achieve the proper

vacuum flowrate. The second problem associated with having the suction hooked up to the main system with all the other vacuum hoses is that, when other suction devices are being used, the scavenger vacuum flowrate drops. To control this, the scavenging vacuum can be connected to a separate system or increase the vacuum flowrate to compensate for the other suction devices when used by the chairside assistant.

Several patients indicated that the Blue and Brown scavengers seemed to leak less than the others. Most reported that the majority of leakage was from around the crown of the nose. The author observed gaps between the edge of the Porter mask and the nose of the patient. The Porter mask was much more rigid and stiffer around the edge than the Blue and Brown masks. A soft and pliable mask is more likely to produce a close, snug fit when a vacuum is applied. A mask with soft, pliable edges is more likely to conform to the sides of the nose. Other recommendations to control nitrous oxide exposure can be found in the NIOSH Technical Information, "Control of Occupational Exposure to N_2O in the Dental Operatory."[1]

Miran 1A

Comment concerning the variability found in the calibration of the Miran 1A is appropriate. This instrument is advertised as a portable instrument used to analyze chemical concentrations in the air. The figures in Appendix A show the difference in calibration curves that

occurred after moving the Miran 1A from one location to another. If the Miran 1A was kept in one location, the calibration curve remained the same. It is recommended that calibration be performed at the sampling site.

Nitrox Dosimeter Comparison

The Nitrox dosimeters provided a second measurement of the relative comparison between the four nitrous oxide scavengers. Side-by-side dosimeter sampling tested for variability between the sampling units.

In using a sample size of 44 paired dosimeters, the mean of the sample differences ($\bar{d}$) and the sample standard deviation of the differences (S_d) were calculated to be 110 $\pm$ 511 ppm. These results were used to calculate a matched pairs, two-tailed t-test based on the t-distribution with n - 1 degrees of freedom (df). Statistical significance was measured at the $\alpha = 0.05$ level. The differences between the paired dosimeters were not statistically significant (paired t-test, $t = 1.42$, $p > 0.10$) for any of the 44 pairs.

In comparing the relationship between the Nitrox dosimeters and the bag samples, a total of 56 pairs were evaluated. From the dosimeters, 44 values were an average of the paired dosimeters and 12 were single dosimeter samples. The mean of the sample differences ($\bar{d}$) and the sample standard deviation of the differences (S_d) were calculated to be 134 $\pm$ 3,108 ppm. These results were used

to calculate a matched pairs, two-tailed t-test based on the t-distribution with n - 1 degrees of freedom (df). Statistical significance was measured at the $\alpha = 0.05$ level. The differences between the Nitrox dosimeters and the bag samples were not statistically significant (paired t-test, $t = 0.323$, $p > 0.10$).

Endnotes

[1]Charles E. Whitcher et al., "Control of Occupational Exposure to Nitrous Oxide in the Dental Operatory," U.S. Department of Health, Education, and Welfare, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 77-171 (April 1977), p. 37.

CHAPTER V

CONCLUSION

Evaluation of the four scavengers used in the dental profession for capturing waste nitrous oxide was performed by a paired multiple comparison of the six possible pairs of scavengers. The results of the study indicated that the six pairs of scavengers were not statistically different at an overall $\alpha = 0.05$ level. Power calculations indicate high probability that a Type II Error resulted, since only 13 of the required 30 patients were evaluated. The study shows evidence of a difference, albeit not a statistically significant one, in air concentration of nitrous oxide achieved by the four scavengers tested. Based on Tables 3-5, effectiveness of the four scavengers in descending order is Blue, Brown, Fraser Harlake, and Porter.

The results of this study indicate that the dental team is exposed to nitrous oxide concentrations that are in excess of the 50 ppm recommended by NIOSH. The results also indicate that even the best scavenger is not achieving the recommended levels. The dentists who use any of these scavengers may be working under a false sense of security. If the scavengers alone are not able to control these nitrous oxide exposures, then other measures must be developed.

The results of the study show that there are no statistically significant differences between the two Nitrox dosimeters when tested simultaneously, nor between the Nitrox dosimeters and the Miran 1A. This is a further indication that the Nitrox dosimeters are a viable means of sampling air concentrations of nitrous oxide.

The study also demonstrated that there was a serious calibration shift in the Miran 1A when it was transported from one location to another.

APPENDIX A

CALIBRATION OF MIRAN 1A

TABLE 6

MIRAN 1A INSTRUMENTATION SETTINGS

Wavelength	4.5 microns
Pathlength	0.75 meters
Dial	0.24
Slit	1.0 millimeter
Range	1A
Coarse	X1
Fine	5.70-5.75
Meter response	1.0 second

TABLE 7

ABSORBANCE/CONCENTRATION TABLE
FOR FIRST CALIBRATION SERIES

N_2O Volume Injected (ml)	N_2O Concentration (ppm)	N_2O Absorbance (Ab U)
0.5	88.6	0.042
1.0	177.3	0.082
2.0	354.6	0.138
5.0	886.5	0.258
10.0	1,773.0	0.410
20.0	3,546.1	0.538
30.0	5,319.2	0.620
50.0	8,865.2	0.698
80.0	14,184.4	0.764
100.0	17,730.5	0.790
110.0	19,530.5	0.800
140.0	24,822.7	0.824
150.0	26,595.7	0.832

TABLE 8

ABSORBANCE/CONCENTRATION TABLE
FOR SECOND CALIBRATION SERIES

N_2O Volume Injected (ml)	N_2O Concentration (ppm)	N_2O Absorbance (Ab U)
0.5	88.6	0.042
1.0	177.3	0.074
2.0	354.6	0.132
3.0	531.9	0.178
5.0	886.5	0.242
10.0	1,773.0	0.354
15.0	2,659.6	0.434
30.0	5,319.2	0.548
60.0	10,638.3	0.642
70.0	12,411.3	0.662
100.0	17,730.5	0.698

TABLE 9

ABSORBANCE/CONCENTRATION TABLE
FOR THIRD CALIBRATION SERIES

N_2O Volume Injected (ml)	N_2O Concentration (ppm)	N_2O Absorbance (Ab U)
0.5	88.6	0.050
1.0	177.3	0.086
2.0	354.6	0.158
3.0	531.9	0.208
5.0	886.5	0.288
10.0	1,773.0	0.450
12.0	2,127.6	0.482
15.0	2,659.6	0.544
30.0	5,319.2	0.696
60.0	10,639.3	0.818
70.0	12,411.3	0.840
100.0	17,730.5	0.866
130.0	23,049.6	0.916

TABLE 10

CALIBRATION COMPARISONS FOR THE MIRAN 1A

	Absorbance	Concentration Expected (E) from Pre-calibrated Gas	Concentration Derived (D) from Calibration Curve	% Difference $\frac{E-D}{E} \times 100$
First Calibration Check				
150 ppm	0.066	150 ppm	142 ppm	+5.30
523 ppm	0.172	523 ppm	501 ppm	+4.20
2,523 ppm	0.466	2,544 ppm	2,549 ppm	-0.20
11,000 ppm	0.724	11,000 ppm	10,946 ppm	+0.49
Second Calibration Check				
150 ppm	0.064	150 ppm	149 ppm	+0.67
486 ppm	0.168	486 ppm	490 ppm	-0.82
2,544 ppm	0.432	2,544 ppm	2,761 ppm	-8.53
11,000 ppm	0.648	11,000 ppm	11,000 ppm	-2.85
Third Calibration Check				
150 ppm	0.074	150 ppm	148 ppm	+1.33
486 ppm	0.194	486 ppm	479 ppm	+1.44
2,544 ppm	0.542	2,544 ppm	2,642 ppm	-3.85
11,000 ppm	0.820	11,000 ppm	10,892 ppm	+0.98

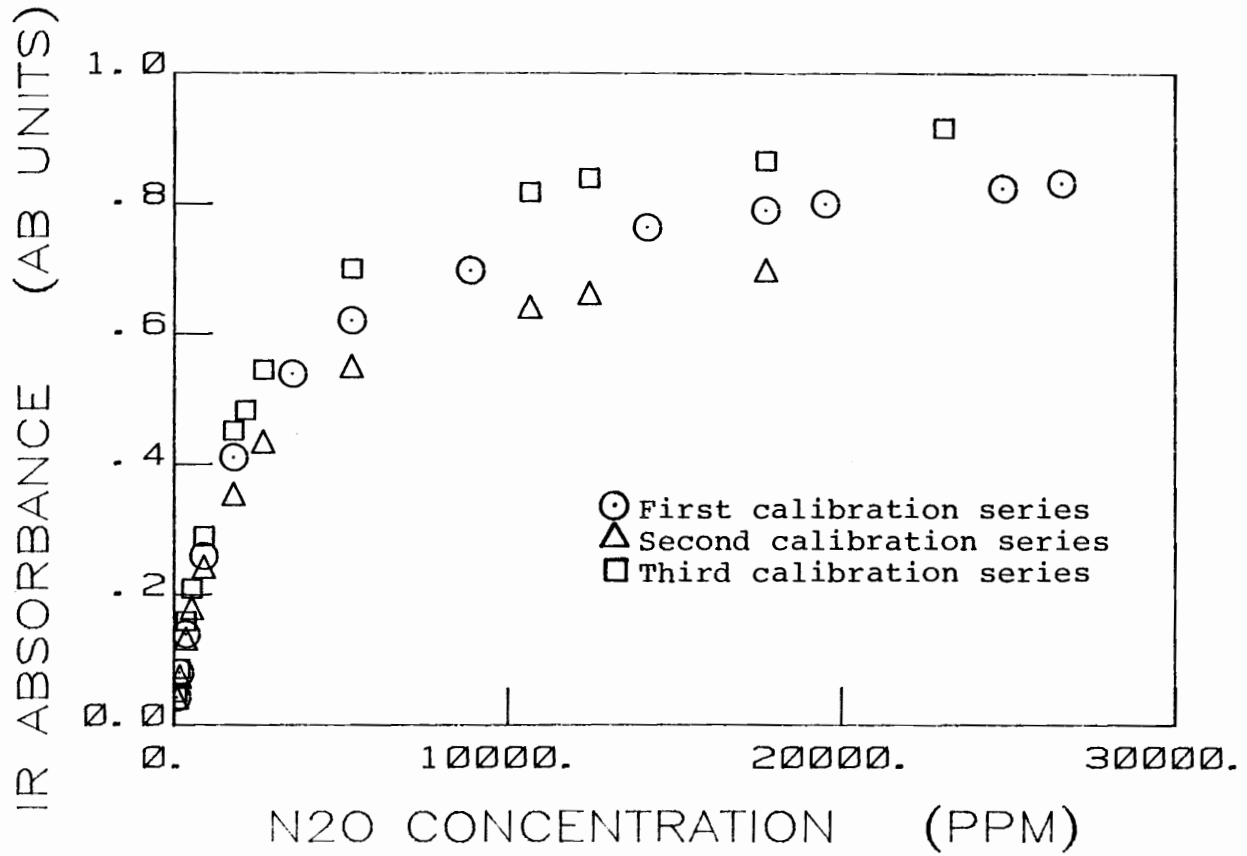


Fig. 3. Full-scale nitrous oxide calibration curves.

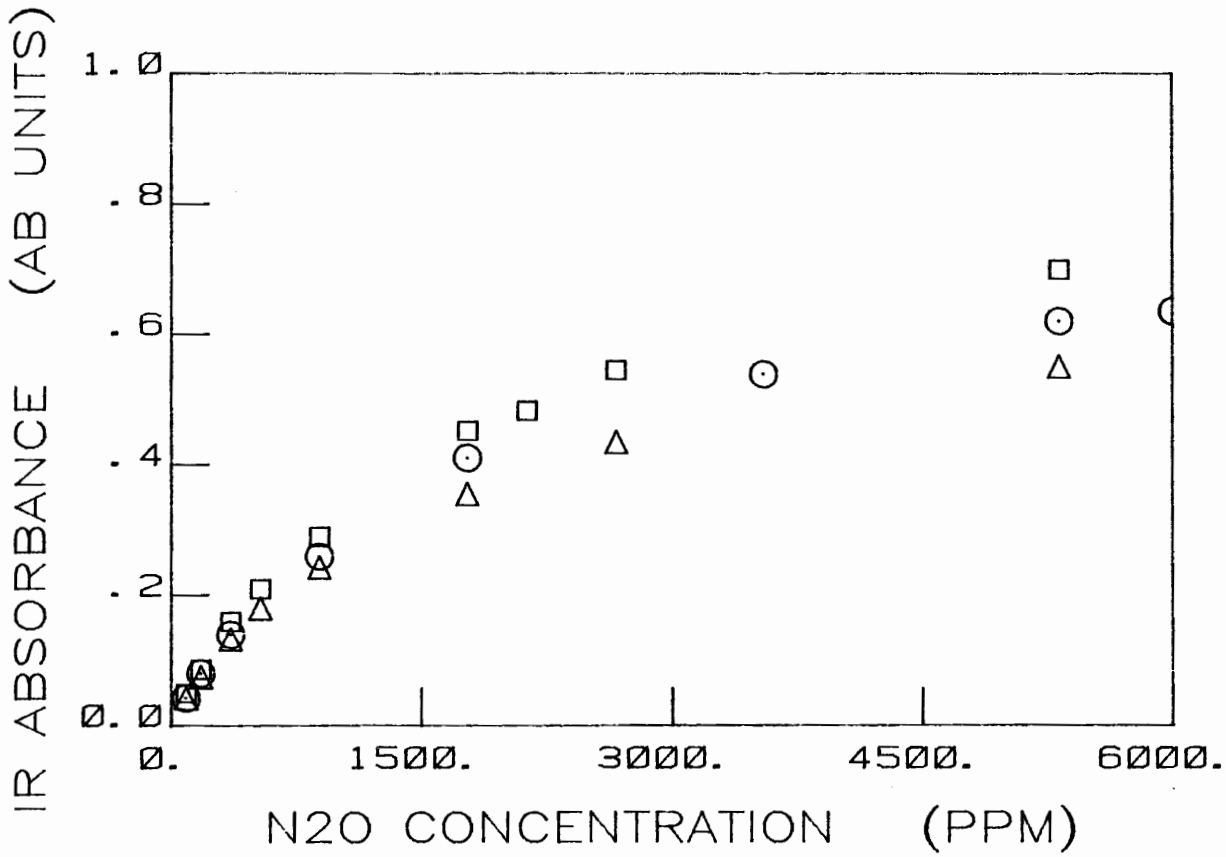


Fig. 4. Enlarged nitrous oxide calibration curves at the lower concentration end.

APPENDIX B

SAMPLING DATA

TABLE 11

TWENTY-MINUTE AIR SAMPLES FROM THE BAG SAMPLES FOR EACH OF THE FOUR SCAVENGERS

Patient	N_2O Concentration in ppm				N_2O Concentration (%) During Administration	Average N_2O Flowrate (lpm)	Average O_2 Flowrate (lpm)
	Brown	Blue	Porter	Fraser Harlake			
1	369	184	13,239	1,276	43	3.00	4.00
2	101	59	8,823	415	46	4.25	5.00
3	397	189	2,620	286	42	3.40	4.75
4	1,325	61	1,702	428	43	2.80	3.75
5	416	428	807	632	45	2.50	3.00
6	342	711	2,434	640	42	2.50	3.50
7	616	283	4,693	573	42	2.50	3.50
8	900	1,921	2,952	1,405	42	2.50	3.50
9	2,224	3,032	24,823	*	43	3.00	4.00
10	2,150	84	1,442	*	43	3.00	4.00
11	249	106	786	2,325	42	2.50	3.50
12	470	234	14,480	514	42	2.50	3.50
13	152	1,210	394	2,403	42	2.50	3.50
14	358	111	4,693	952	43	3.00	4.00
15	701	365	2,344	286	43	3.00	4.00
$\bar{X} \pm SD$ (N = 13)	492 ± 347	451 ± 545	$4,613 \pm 4,668$	933 ± 724			

*Did not obtain the last samples of patients 9 and 10 due to equipment failure; therefore, all samples of patients 9 and 10 were not included in the calculation of the $\bar{X} \pm SD$.

TABLE 12

TWENTY-MINUTE AIR SAMPLES FROM THE NITROX DOSIMETERS FOR EACH OF THE FOUR SCAVENGERS

Patient	N_2O Concentration in ppm				N_2O Concentration (%) During Administration	Average N_2O Flowrate (lpm)	Average O_2 Flowrate (lpm)
	Brown	Blue	Porter	Fraser Harlake			
1	*	179**	3,168**	2,164**	43	3.00	4.00
2	1,482**	105**	20,215**	297	46	4.25	5.00
3	*	225**	14,463	230	42	3.40	4.75
4	2,571**	75	1,176	291**	43	2.80	3.75
5	520**	472**	981**	450	45	2.50	3.00
6	797	566	2,221	714	42	2.50	3.50
7	366	192	3,499	438	42	2.50	3.50
8	802**	1,450	2,386	1,228	42	2.50	3.50
9	1,288	2,393	14,766	4,550	43	3.00	4.00
10	2,097	37	1,092	352	43	3.00	4.00
11	168	103	716	2,122	42	2.50	3.50
12	818	218	7,462	522	42	2.50	3.50
13	128	1,000	334	2,022	42	2.50	3.50
14	354	196	3,434	812	43	3.00	4.00
15	901	250	2,244	566	43	3.00	4.00
$\bar{X} \pm SD$ (N = 13)	946±740	543±692	4,656±6,086	1,105±747			

*Had not yet received the Nitrox dosimeters when the first samples of patients 1 and 3 were tested; therefore, all samples of patients 1 and 3 were not included in the calculation of the $\bar{X} \pm SD$.

**Single dosimeter tests; all the others were an average of two Nitrox dosimeters taped together.

TABLE 13

COMPARISON OF THE NITROX DOSIMETERS
THAT WERE TAPED TOGETHER

Patient	N_2O Concentration in ppm				Patient	N_2O Concentration in ppm			
	Brown	Blue	Porter	Fraser Harlake		Brown	Blue	Porter	Fraser Harlake
1a	*	179	3,168	2,164	9a	1,473	2,138	15,701	4,451
1b	*	*	*	*	9b	1,103	2,648	13,830	4,650
2a	1,482	105	20,215	291	10a	2,161	37	1,115	373
2b	*	*	*	303	10b	2,033	37	1,070	303
3a	*	225	14,463	229	11a	134	100	699	1,992
3b	*	*	*	231	11b	202	106	734	2,252
4a	2,571	102	1,108	291	12a	676	207	8,436	489
4b	*	48	1,245	*	12b	960	229	6,487	554
5a	520	472	981	621	13a	130	1,052	379	2,114
5b	*	*	*	280	13b	125	947	288	1,930
6a	1,184	540	2,404	701	14a	384	198	3,565	779
6b	410	593	2,038	726	14b	323	195	3,304	846
7a	369	200	4,236	395	15a	605	154	2,194	332
7b	363	185	2,762	481	15b	1,197	347	2,293	799
8a	802	1,397	2,417	1,223					
8b	*	1,503	2,356	1,232					

*Tests in which the Nitrox dosimeter had not been used during the sampling.

SELECTED BIBLIOGRAPHY

Askog, V., and Harvald, B. "Teratogen Effect of Inhalations-Anestetika." Saertyk Nord Med 3 (1970): 490-500.

Bashford, Alice B., and Fink, B. Raymond. "The Teratogenicity of Halothane in the Rat." Anesthesiology 29 (December 1968):1167-1173.

Beaulieu, Harry J. "Evaluation of Nitrous Oxide Scavenging Systems." Unpublished manuscript, Department of Community and Environmental Health, Boise State University, Boise, Idaho.

Bruce, David L., and Wingard, Daniel W. "Anesthesia and the Immune Response." Anesthesiology 34 (March 1971): 271-282.

Bruce, David L.; Bach, Mary Jean; and Arbit, Jack. "Trace Anesthetic Effects on Perceptual, Cognitive, and Motor Skills. Anesthesiology 40 (May 1974):453-458.

Bruce, David L., and Bach, Mary Jean. "Psychological Studies of Human Performance As Affected by Traces of Enflurane and Nitrous Oxide." Anesthesiology 42 (February 1975):194-196.

Campbell, Robert L.; Hannifan, Michael A.; Reist, Rarker C.; and Gregg, John M. "Exposure to Anesthetic Waste Gas in Oral Surgery." Journal of Oral Surgery 35 (August 1977):625-630.

Cleaton-Jones, P.; Austin, J. C.; Moyes, D. G.; Shaw, R.; and Crichton, R. "Nitrous Oxide Contamination in Dental Surgeries Using Relative Analgesia." British Journal of Anaesthesia 50 (1978):1019-1023.

Cohen, Ellis N.; Bellville, J. Weldon; and Brown, Byron W. "Anesthesia, Pregnancy, and Miscarriage: A Study of Operating Room Nurses and Anesthetists." Anesthesiology 35 (October 1971):343-347.

Cohen, Ellis N.; Brown, Byron W.; Bruce, David L. Cascorbi, Helmut F.; Corbett, Thomas H.; Jones, Thomas W.; and Whitcher, Charles E. "Occupational Disease Among Operating Room Personnel: A National Study." Anesthesiology 41 (October 1974):321-339.

Cohen, Ellis N.; Brown, Byron W.; Bruce, David L.; Cascorbi, Helmut F.; Corbett, Thomas H.; Jones, Thomas W.; and Whitcher, Charles E. "A Survey of Anesthetic Health Hazards Among Dentists." The Journal of the American Dental Association 90 (June 1975):1291-1296.

Cohen, Ellis N.; Brown, Byron W.; Wu, Marion L.; Whitcher, Charles E.; Brodsky, Jay B.; Gift, Helen C.; Greenfield, William; Jones, Thomas W.; and Driscoll, Edward J. "Occupational Disease in Dentistry and Chronic Exposure to Trace Anesthetic Gases." The Journal of the American Dental Association 101 (July 1980):21-31.

Colton, Theodore. Statistics in Medicine. Boston: Little, Brown and Company, 1974.

Corbett, Thomas H.; Cornell, R. G.; Endres, J. L.; and Millard, R. I. "Effects of Low Concentrations of Nitrous Oxide on Rat Pregnancy." Anesthesiology 39 (September 1973):299-301.

Corbett, Thomas H.; Cornell, Richard G.; Lieding, Keith; and Endres, Judy L. "Incidence of Cancer Among Michigan Nurse-Anesthetists." Anesthesiology 38 (March 1973):260-263.

Corbett, Thomas H.; Cornell, Richard G.; Endres, Judy L.; and Lieding, Keith. "Birth Defects Among Children of Nurse-Anesthetists." Anesthesiology 41 (October 1974): 341-344.

Eastwood, Douglas W.; Green, C. D.; Lambdin, M.A.; and Gardner, Richard. "Effect of Nitrous Oxide on the White-Cell Count in Leukemia." The New England Journal of Medicine 268 (February 7, 1963):297-299.

Eastwood, Douglas W. Nitrous Oxide. Philadelphia: F. A. Davis Company, 1964.

Fink, B. Raymond; Shepard, T. H.; and Blandau, R. J. Teratogenic Activity of Nitrous Oxide." Nature 214 (April 8, 1967):146-149.

Knill-Jones, R. P.; Moire, D. B.; and Rodrigues, L. V. Anaesthetic Practice and Pregnancy: A Controlled Survey of Women Anesthetists in the United Kingdom." The Lancet 2 (November 1972):1326.

Millard, Robert I., and Corbett, Thomas H. "Nitrous Oxide Concentration in the Dental Operatory." Journal of Oral Surgery 32 (August 1974):593-594.

Miller, Rupert G. Simultaneous Statistical Inference. New York: Springer-Verlag, 1981.

National Institute of Occupational Safety and Health. Criteria for a Recommended Standard--Occupational Exposure to Waste Anesthetic Gases and Vapors. DHEW (Niosh) Publication No. 77-140 (1977).

Parbrook, Geoffrey, D. "Leucopenic Effects of Prolonged Nitrous Oxide Treatment." British Journal of Anaesthesia 39 (1967):119-127.

Scaramella, J.; Allen, G. D.; Adams, D.; and Randall, F. "Nitrous Oxide Pollution Levels in Oral Surgery Offices." Journal of Oral Surgery 36 (June 1978): 441-443.

Smith, Bradley E.; Gaub, Margaret L.; and Moya, Frank. "Investigation into the Teratogenic Effects of Anesthetic Agents: the Fluorinated Agents." Anesthesiology 26 (April 1965):260-261.

Swenson, Ralph D. "Scavenging of Dental Anesthetic Gases." Journal of Oral Surgery 34 (March 1976):207-214.

Vaisman, A. I. "Working Conditions in Surgery and Their Effects on the Health of Anesthesiologists." Eksp Khir Anesteziol 3 (1967):44-49.

Whitcher, Charles E.; Zimmerman, David C.; and Piziali, Robert L. "Control of Occupational Exposure to N_2O in the Dental Operatory." U.S. Department of Health, Education and Welfare, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health. DHEW (NIOSH) Publication No. 77-171 (April 1977).

Whitcher, Charles E.; Zimmerman, Donald C.; Tonn, Elverne M.; and Piziali, Robert L. "Control of Occupational Exposure to Nitrous Oxide in the Dental Operatory." The Journal of American Dental Association 95 (October 1977):763-776.